

(19)



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(11)

EP 0 848 491 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention
of the grant of the patent:
03.09.2003 Bulletin 2003/36

(51) Int Cl.7: **H02P 7/05**

(21) Application number: **97308970.9**

(22) Date of filing: **07.11.1997**

(54) **Hysteresis current controller for a reluctance machine**

Hysterese-Regelung des Stromes einer Reluktanz-Maschine

Commande hystérésis à courant pour une machine à réluctance

(84) Designated Contracting States:
BE DE FR GB IT

(30) Priority: **12.12.1996 GB 9625831**

(43) Date of publication of application:
17.06.1998 Bulletin 1998/25

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(56) References cited:
EP-A- 0 635 931 **US-A- 4 933 621**
US-A- 5 467 025

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Description

[0001] This invention relates to hysteresis current controllers for reluctance machines.

[0002] The switched reluctance machine is an example of an electrical load having a variable inductance. It comprises a stator, defining stator poles, and a rotor, defining rotor poles. Energising windings are wound in relation to the stator poles. Typically, groups of the windings are energised simultaneously as a phase. Energisation of the windings of the or each phase is controlled by switching a source of electrical power in a phase circuit including the phase windings. The reluctance machine can be operated as either a motor or a generator. A description of switched reluctance machines and their control can be found in the article 'The Characteristics, Design and Applications of Switched Reluctance Motors and Drives' by Stephenson and Blake, presented at the PCIM '93 Conference and Exhibition at Nurnberg, Germany, June 21-24, 1993.

[0003] At low speed, the torque developed by the switched reluctance motor is usually controlled by adjusting the amount of current in the phase windings, i.e. the motor is said to be "current fed". Usually, a voltage source is the most practicable means of deriving electrical power and so a current controller is required. The current controller controls the states of power switches to apply a voltage across the phase winding so as to establish the required current in the phase winding. The performance of the current controller, in both transient and steady-state senses, will be affected by the nature of the electrical load which the phase circuit presents.

[0004] Unlike d.c. and induction motors, the winding of the switched reluctance machine has neither a constant inductance nor exhibits a simple 'motional EMF' effect. A mathematical expression for the electrical behaviour of the switched reluctance phase circuit can be described as:

$$v = iR + l(i, \theta) \frac{di}{dt} + i\omega \frac{\partial L}{\partial \theta}(i, \theta) \quad (1)$$

where:

- v is the phase voltage
- R is the phase resistance
- i is the phase current
- L is the phase inductance
- l is the incremental phase inductance
- ω is the rotational speed
- θ is the rotor angle relative to the stator

[0005] The three different terms in equation 1 may be explained as follows :

- the first term (iR) is that due to the resistive voltage drop in the phase winding;
- the second term ($l(i, \theta) di/dt$) is proportional to the

rate of change of phase current and is due to the effective inductance of the phase, i.e. the incremental inductance. This term can be seen to be non-linear in nature as the incremental inductance is a function of both current and angle. A plot showing the variation in the incremental inductance of a sample switched reluctance machine is shown in Figure 1 of the drawings which is a graph of incremental inductance against rotor angle for various values of phase current. This shows that incremental inductance can vary by over 10 to 1 for a machine operated over a wide range of currents, for example a servo-drive;

the last term of equation 1 ($i\omega \partial L(i, \theta)/\partial \theta$) can be seen to be proportional to the rotational speed (ω) and is therefore sometimes called the "motional EMF". It arises because the phase inductance is a function of rotor angle and therefore varies with time as the machine rotates. It is also non-linear in nature and depends on how the phase inductance varies with rotor angle at a particular phase current and rotor angle. By way of illustration, Figure 2 shows the motional EMF for a switched reluctance machine for a given speed and various values of phase current.

[0006] One form of current control which is often used with switched reluctance machines is hysteresis current control. It is widely used due to the high bandwidth control attainable and the simplicity of its implementation. Forms of hysteresis current control are described in EP-A-0635931.

[0007] Hysteresis current control works by changing the conductive state of power switches in the current controller whenever the current reaches a threshold level above or below the demanded current. The gap between the upper and lower thresholds is known as the hysteresis band. A simple hysteresis current control function is shown in the graph of Figure 3 where the voltage applied is of a constant magnitude, but opposite polarity, for the on and off states of the power switches and the current is assumed to rise and fall in a linear manner. In practice, this is not the case but serves to illustrate generally the hysteresis chopping waveform in which the current is free to vary within the limits of the upper and lower thresholds and is controlled by switching if it exceeds either threshold.

[0008] Simplified expressions for the on and off times (shown in Fig.3 as t_{on} and t_{off}) may be used to derive the following equation:

$$f = (V^2 - i_{av}^2 R^2 - 2i_{av} R \epsilon - \epsilon^2) / 2l_i V \quad (2)$$

where:

f is the switching frequency

V is the DC link voltage
 i_{av} is the average phase current
 R is the phase resistance
 ε is the 'motional EMF'
 l is the incremental inductance
 i_h is the width of the hysteresis band

[0009] Equation 2 assumes that the instantaneous phase current will rise and fall in a linear manner as stated above. While this is not completely accurate, provided the switching period is short compared with the time constant of the inductive load (which is usually the case for a switched reluctance machine) the error due to this approximation to linearity is acceptably small.

[0010] It can be seen from equation 2 that the switching frequency will vary according to the particular phase circuit parameters unless the width of the hysteresis band is adjusted accordingly. In practice, this is not done as it would require the storage of significant amounts of data based on the electromagnetic characteristics of the machine. It would also require the sensing of rotor position and speed, in addition to current, and very rapid data processing to determine the correct width of the hysteresis band. Thus, when conventional hysteresis current control is used, the power switching frequency varies and undesirable acoustic noise often results.

[0011] In the simplest form of hysteresis current control, a fixed hysteresis band is used, centred around the demanded current. It is set to ensure that the power switching frequency is such that the maximum acceptable switching losses are not exceeded under any operating conditions of the drive. For example, in a positioning servo-drive based on a switched reluctance machine which is required to operate into overload, this will necessitate having a comparatively wide hysteresis band to cope with the very low incremental inductance encountered at high currents. This in turn can cause significant steady-state error at low average currents, because the positive and negative excursions about the demand current become unequal as soon as the lower bound of the hysteresis band reaches zero current.

[0012] It is one object of the invention to reduce the amount of acoustic noise resulting from the control of a switched reluctance machine having a varying power switching frequency.

[0013] It is another object of the invention to optimise the hysteresis band for a given set of operating conditions in hysteresis current control of a switched reluctance machine.

[0014] The invention is defined in the accompanying independent claims 1 and 12 to a method of controlling current and to a switched reluctance machine system, respectively. Preferred features of the invention are recited in the dependent claims.

[0015] A frequency controller according to the invention is used for active adjustment of the width of the hysteresis band in order to regulate the switching frequency. In this way, the switching frequency can be main-

tained more closely to a preferred rate. It is also possible to control more accurately the phase current in a switched reluctance machine down to lower currents using the current controller of the invention.

[0016] To control the current a signal indicative of current is required. This may be a feedback signal of current or a signal derived from another variable which is indicative of current.

[0017] The present invention can be put into practice in various ways, some of which will now be described by way of example with reference to the accompanying drawings in which :

Fig.1 is a graph of incremental inductance against the electrical angle of rotation over half a cycle of the switched reluctance machine for various phase current values;

Fig.2 is a graph of motional EMF against electrical angle of rotation over half a cycle of a switched reluctance machine for various phase current values; Fig.3 is a graphical illustration of phase current switching between hysteresis current thresholds;

Fig.4 is a generalised schematic block diagram of a current controller according to the invention;

Fig.5 is a more detailed schematic block diagram of a first embodiment of a controller of the invention; and

Fig.6 is a more detailed schematic block diagram of a second embodiment of the controller of the invention.

[0018] Referring to Fig.4, a switched reluctance drive includes a hysteresis current controller, comprising a first error amplifier 10 which provides an error signal I_e which is indicative of the difference between a motor current demand signal I_d and a motor current feedback signal I_f . The signal I_f is derived from the phase current in the stator winding of the switched reluctance machine 28 by a current transducer. The error signal I_e is supplied as an input to a hysteresis control device 14. The output of the device 14 is a switch firing signal T which is arranged to activate selectively the power switches of a particular phase circuit of the motor by which voltage is applied to the phase windings.

[0019] In this embodiment the timing of the phase conduction periods for each phase and the phase sequence are controlled by a controller 22 that demands the appropriate current according to the position information from the rotor of the machine 28. In this embodiment, the rotor position information is derived from the rotor shaft 23 by a position transducer 25 and a signal processor 27. Those skilled in the art will recognise that other forms of rotor position detection can be used, e.g. as taught in US 5,467,025. Fig.4 illustrates only one phase switching circuit 24 for the machine 28. In general, the machine will have other phases, each with its own switching circuits. Alternatively, the switching circuits can be shared by two or more phases. The timing and

sequencing of the switching is conventional to the switched reluctance machine art and will not be described in further detail here. The embodiment of Fig.4 can notionally be sub-divided into a current control loop which is conventional in the art and a frequency control loop. It will be appreciated by one skilled in the art that most of the blocks of Fig.4 could be implemented in either hardware or software.

[0020] The output of the hysteresis control device 14 is the firing signal for the phase of the switched reluctance machine 28. Thus, timed to each phase conduction period, the hysteresis control device 14 will provide a series of firing pulses in order to control the voltage across the phase winding to regulate the current in the winding between the upper and lower thresholds of the hysteresis band.

[0021] A second error amplifier 16 provides a frequency error output F_e which is indicative of the difference between a reference switching frequency F_r and a frequency feedback signal F_f . The signal F_r need not be constant - it can be under the control of a user or it can be programmed to vary in response to either some other event or a cyclical pattern of events. The signal F_f is derived by a frequency sensor 18 from the switch firing output of the hysteresis control device 14.

[0022] The frequency error signal F_e is applied to a frequency controller 20 which provides a hysteresis width I_h to the hysteresis control device 14.

[0023] The signal I_d is of a sign and magnitude that is proportional to the level of current demanded. If the width of the hysteresis band were to remain fixed, then the switching frequency of the current controller would vary according to the particular operating point (as defined above in equation 2).

[0024] By sensing the frequency with which switching occurs due to the current error signal I_e traversing one of the hysteresis thresholds, the controller according to the invention is able to adjust the upper and/or lower hysteresis limits so that the average switching frequency is controlled to centre on the predetermined reference frequency F_r .

[0025] The frequency controller varies the hysteresis width I_h slowly compared with the rate at which phase current is controlled. In this way, the average switching frequency is regulated, whatever the particular phase operating conditions. This will be explained in more detail below.

[0026] A more detailed embodiment of the invention is shown in Figure 5. The control of the switching frequency is implemented by the use of a phase locked loop (PLL) which incorporates the hysteresis control device 14 as the voltage controlled oscillator (VCO) of the PLL. The frequency comparator is a type II digital phase sensitive detector (PSD) 30. The type II detector is used because it allows correct operation despite the duty cycle of F_r and F_f being different. It will also be noted that the feedback frequency signal F_f is applied to the non-inverting input + of the detector 30 and the reference

frequency F_r is applied to the inverting input - of the detector. This takes account of the inverse relationship between the width of the hysteresis band and the switching frequency, i.e. as the hysteresis band increases, the switching frequency decreases at a particular operating point.

[0027] A proportional-plus-integral (P+I) compensator 32 is used as the frequency controller. It receives the error frequency signal F_e from the PSD 30. It will be appreciated by the skilled person that, by the nature of the cyclical excitation current supplied to a switched reluctance machine, current does not usually flow continuously in any one phase, unlike, for example, the case of the three-phase induction motor. Thus, in between periods of energisation of the windings of each of the phases, the VCO function of the hysteresis control device 14 is effectively disabled. This also happens when the rate of change of demand current exceeds the slew limit of the system to react, the supply voltage determining the rate of change of excitation current. Thus, due to the intermittent nature of the phase excitation current, it is of significant advantage if the PLL is able to acquire lock rapidly and reliably at the start of each phase excitation period. It is also advantageous if the PLL is able to 'ride through' transient disturbances in the controlled current that give rise to the PLL losing lock, such that rapid reacquisition of lock is achieved. The control action to allow this to happen is described below.

[0028] In Figure 5 an adjustable offset I_o is provided through an adder 34 on the control signal output from the P+I compensator 32. The value of the offset I_o is an initial estimation of the appropriate width of the hysteresis band required at the start of the excitation period. By providing the offset, the PLL does not have to start from zero hysteresis width in order to achieve lock and acquisition can be more rapid as a result.

[0029] A limiter 36 is applied to the control output of the adder 34 so that the excursions of the hysteresis band are confined between fixed limits so that excessive switching frequencies, which may occur during lock acquisition, are avoided. Having such a non-linear element within the control loop of the PLL also aids lock acquisition.

[0030] The system is also designed to assist the PLL to provide a smooth control function in the presence of rapid fluctuations in demand current. By 'rapid', is meant at such a rate that the switching frequency drops to zero as the phase current is slew limited due to the finite forcing voltage available from the power supply V_{DC} . This is achieved by a current slew limit detector 38 which receives the current error signal I_e and the output of the limiter which is the hysteresis width signal I_h . The output of the detector 38 is supplied to one input of a two-input AND gate 39. The other input to the AND gate 39 is the output of the PSD 30. The output of the AND gate 39 is the output F_e of the PSD 30 gated by the slew limit detector 38 and supplied to the P+I compensator 32. When the rate of change of the error current signal I_e is such

that slew limiting results, the output of the PSD 30 is disabled from being applied to the P+I compensator 32. Once any such transient condition has passed, the slew rate detector 38 output changes state to enable the output of the PSD 30 to be applied to the P+I compensator. This prevents the P+I controller 32 from reacting to the VCO action of the hysteresis current controller having been disabled during slew limit. It also allows lock to be re-established relatively rapidly, the PLL having ridden through the transient condition.

[0031] Lastly, the speed at which the PLL is able to achieve lock is assisted by a reset input I_r to the P+I compensator 32 which resets the integral term to zero whenever there is no phase energisation for the system to control, i.e. the reset signal is timed to remove the integral term outside a phase conduction period.

[0032] This embodiment of the invention uses a phase locked loop incorporating the hysteresis control device as the voltage controlled oscillator (VCO). The gain of the VCO in this implementation of a PLL will vary by a significant amount according to the particular operating conditions. This will cause the dynamic response of the PLL to vary according to the operating conditions, but not the response of the current regulating loop providing the firing signals to the phase switches. The invention exploits the fact that a signal (either digital or analogue) of the desired switching frequency can be used as the input to a feedback control loop which adjusts the hysteresis band in response to the monitored switching frequency.

[0033] The bandwidth of the PLL control of the frequency is preferably significantly narrower than that of the current control loop. For example, it is considered practicable for the PLL bandwidth to be a factor of about 10 narrower than that of the current control loop. The response of the PLL for the purposes of controlling frequency is based on an average of a number of periods of the switching frequency. If the PLL were too responsive there would be a risk of system instability as one control loop attempted to react to changes in the other loop.

[0034] Fig.6 shows an alternative form of the invention which is a more fully digital embodiment detecting switching period instead of frequency. The switch firing signal T is applied to a period measurement device 40. The device determines the switch actuation period P_f by counting the number of transitions of a digital high frequency clock 42 during an enabled period corresponding to the switch actuation period. A digital subtractor 44 derives the difference between the output P_f of the measurement device 40 and a reference switching period signal P_r . The subtraction can take the form of well-known 2's complement adders.

[0035] The offset I_o is applied to the output of a digital P+I compensator 46 by a digital adder 48. A digital limiter 50 defines the maximum and minimum widths of the hysteresis band. A digital to analogue converter 52 receives the digital output of the limiter 50 to produce the

analogue hysteresis band control signal I_h

[0036] In other respects, the embodiment of Fig.6 is equivalent to Fig.5. In both cases, the desired switching frequency is controlled by a loop that is added to the current control loop. In practice, this implementation could largely be done in software.

[0037] While the invention has been described in connection with the illustrative embodiments discussed above, those skilled in the art will recognise that many variations may be made without departing from the present invention. While analogue and digital phase locked loops are described above, it will be apparent that other forms of control loop could be used, as known in control systems art. Also, other forms of control regime other than the proportional-plus-integral action described above could be used. For example, a pole zero approximation could be used. It will be realised by the skilled person that parts of the circuit could be implemented in either digital, analogue or software form. Accordingly, the above description of embodiments is made by way of example and not for the purposes of limitation. The present invention is intended to be limited only by the scope of the following claims.

Claims

1. A method of controlling current in a switched reluctance machine (28) having at least one winding, the method comprising:
 - deriving a current signal (I_f) indicative of the current;
 - comparing the current signal with a signal indicative of a desired current to produce an error signal;
 - setting a single hysteresis band (i_h) about a level (i_{av}) indicative of a desired current;
 - switching (24) the current when the error signal indicates that the current has traversed a limit of the single hysteresis band so as to return the current to within the hysteresis band; and
 - monitoring the frequency of switching and adjusting the width of the hysteresis band in response to the monitored frequency so as to adjust the frequency of switching while the machine is in operation.
2. A method as claimed in claim 1 in which the hysteresis band is adjusted in response to the monitored frequency to maintain a switching frequency substantially at a desired rate.
3. A method as claimed in claim 1 or 2, including comparing the monitored frequency (F_f) with a reference frequency (F_r) to produce a frequency error signal (F_o) and generating a control signal based on the frequency error signal and a control function (PI).

4. A method as claimed in claim 3 in which the control function is a proportional-plus-integral control
5. A method as claimed in claim 4 in which the integral term (I) of the control function is set to zero when no current flows in the winding.
6. A method as claimed in any of claims 3 to 5 in which an offset (I_o) is added to the control signal.
7. A method as claimed in any of claims 1 to 6, including limiting the minimum and/or maximum width of the hysteresis band.
8. A method as claimed in any of claims 1 to 7, including deriving (38) a signal indicative of the slew rate of the current and disabling (39) the control signal when the slew exceeds a predetermined rate.
9. A method as claimed in any of claims 1 to 8, including comparing a desired current level signal (I_d) with the current signal (I_f) to derive a current error signal (I_e), the hysteresis band being set around zero current error.
10. A method as claimed in claim 1 in which the current signal is a feedback signal (I_f).
11. A switched reluctance machine system comprising a switched reluctance machine (28) having a rotor, a stator and at least one phase winding;

means for deriving a current signal (I_f) indicative of current in the winding;

switch means (24) actuatable to apply a voltage to the winding;

error detector means (10) for comparing the current signal with a signal indicative of a desired current (I_d) to produce an error signal (I_e);

hysteresis control means (14) arranged to receive the error signal and being operable to actuate the switch means when the error signal indicates that the current has exceeded an upper or lower hysteresis threshold of a single hysteresis band (i_h) to return the current to within the hysteresis band; and

frequency control means (20) operable to monitor the frequency of switching and to adjust the width of the hysteresis band in response to the monitored frequency so as to adjust the frequency of switching while the machine is in operation.
12. A system as claimed in claim 11, including monitoring means (18) for monitoring the switching frequency to produce an output (F_f), the frequency control means being operable to generate a frequency control signal based on the said output, the

hysteresis control means being responsive to the frequency control signal to adjust the width of the hysteresis band.

13. A system as claimed in claim 12 in which the hysteresis control means are responsive to the frequency control signal to adjust the hysteresis band to maintain the switching frequency substantially at a desired rate.
14. A system as claimed in claim 13 in which error detector means (16) are arranged to produce an frequency error signal (F_e) according to the difference between the output of the monitoring means and the desired rate.
15. A system as claimed in claim 14 in which the frequency control means comprise a proportional-plus-integral controller (32).
16. A system as claimed in any of claims 12 to 15 including offset means (34) arranged to add an offset (I_o) to the frequency control signal.
17. A system as claimed in any of claims 12 to 16, including slew rate monitoring means (38) operable to monitor the slew rate of the current in the winding and to disable the frequency control signal when the current slew exceeds a predetermined rate.
18. A system as claimed in any of claims 11 to 16, including means for setting the integral control term of the controller to zero when no current flows in the winding.
19. A system as claimed in any of claims 11 to 18, including a limiter (36) arranged to limit the minimum and/or maximum width of the hysteresis band.

Patentansprüche

1. Verfahren zur Regelung des Stroms in einer geschalteten Reluktanz-Maschine (28), die mindestens eine Wicklung aufweist, welches Verfahren aufweist:

Herleiten eines den Strom kennzeichnenden Stromsignals (I_f);

Vergleichen des Stromsignals mit einem einen gewünschten Strom kennzeichnenden Signal, um ein Fehlersignal zu erzeugen;

Setzen eines einzelnen Hysteresebandes (i_h) um einen für einen gewünschten Strom kennzeichnenden Pegel (i_{av});

Schalten (24) des Stroms, wenn das Fehlersignal anzeigt, dass der Strom eine Grenze des einzelnen Hysteresebandes überquert hat, um

- den Strom in das Hystereseband zurückzubringen; und
Überwachen der Frequenz des Schaltens und
Einstellen der Breite des Hysteresebandes in
Antwort auf die überwachte Frequenz, um die
Frequenz des Schaltens einzustellen, während
die Maschine in Betrieb ist.
2. Verfahren nach Anspruch 1, bei dem das Hystereseband in Antwort auf die überwachte Frequenz eingestellt wird, um eine Schaltfrequenz im wesentlichen bei einer gewünschten Rate zu halten.
3. Verfahren nach Anspruch 1 oder 2, mit einem Vergleichen der überwachten Frequenz (F_r) mit einer Referenzfrequenz (F_r), um ein Frequenzfehlersignal (F_e) zu erzeugen, und einem Erzeugen eines Steuersignals basierend auf dem Frequenzfehlersignal und einer Steuerfunktion (PI).
4. Verfahren nach Anspruch 3, bei dem die Steuerfunktion eine Proportional-Plus-Integral Steuerfunktion (PI) ist.
5. Verfahren nach Anspruch 4, bei dem der Integralausdruck (I) der Steuerfunktion auf Null gesetzt wird, wenn kein Strom in der Wicklung fließt.
6. Verfahren nach irgendeinem der Ansprüche 3 bis 5, bei dem ein Offset (I_0) dem Steuersignal hinzuaddiert wird.
7. Verfahren nach irgendeinem der Ansprüche 1 bis 6, mit einem Begrenzen der minimalen und/oder maximalen Breite des Hysteresebandes.
8. Verfahren nach irgendeinem der Ansprüche 1 bis 7, mit einem Herleiten (38) eines Signals, das für eine Anstiegsgeschwindigkeit des Stroms kennzeichnend ist, und Abschalten (39) des Steuersignals, wenn die Anstiegsgeschwindigkeit eine vorbestimmte Rate übersteigt.
9. Verfahren nach irgendeinem der Ansprüche 1 bis 8, mit einem Vergleichen eines gewünschten Strompegelsignals (I_d) mit dem Stromsignal (I_r), um ein Stromfehlersignal (I_e) herzuleiten, wobei das Hystereseband um einen Nullstromfehler gesetzt ist.
10. Verfahren nach Anspruch 1, bei dem das Stromsignal ein Rückführsignal (I_f) ist.
11. Geschaltetes Reluktanz-Maschinensystem, aufweisend eine geschaltete Reluktanz-Maschine mit einem Rotor, einem Stator und mindestens einer Phasenwicklung;
- ein Mittel zum Herleiten eines Stromsignals (I_r), das für den Strom in der Wicklung kennzeichnend ist;
ein Schaltmittel (24), das betreibbar ist, um eine Spannung an die Wicklung anzulegen;
ein Fehlerdetektionsmittel (10) zum Vergleichen des Stromsignals mit einem Signal, das für einen gewünschten Strom (I_d) kennzeichnend ist, um ein Fehlersignal (I_e) zu erzeugen;
ein Hysteresesteuermittel (14), das angeordnet ist, um das Fehlersignal zu empfangen, und das betreibbar ist, um das Schaltmittel anzu steuern, wenn das Fehlersignal anzeigt, dass der Strom einen oberen oder unteren Hystereseschwellenwert eines einzelnen Hysteresebandes (I_h) überschritten hat, um den Strom in das Hystereseband zurückzubringen; und
ein Frequenzsteuermittel (20), das betreibbar ist, um die Frequenz des Schaltens zu überwachen, und die Breite des Hysteresebandes in Antwort auf die überwachte Frequenz einzustellen, um die Schaltfrequenz einzustellen, während die Maschine in Betrieb ist.
12. System nach Anspruch 11, mit einem Überwachungsmittel (18) zur Überwachung der Schaltfrequenz, um ein Ausgangssignal (F_r) zu erzeugen, wobei das Frequenzsteuermittel betreibbar ist, um ein Frequenzsteuersignal basierend auf dem Ausgangssignal zu erzeugen, wobei das Hysteresesteuermittel auf das Frequenzsteuersignal antwortet, um die Breite des Hysteresebandes einzustellen.
13. System nach Anspruch 12, bei dem das Hysteresesteuermittel auf das Frequenzsteuersignal antwortet, um das Hystereseband einzustellen, um die Schaltfrequenz im wesentlichen bei einer gewünschten Rate zu halten.
14. System nach Anspruch 13, bei dem ein Fehlerdetektormittel (16) angeordnet ist, um ein Frequenzfehlersignal (F_e) gemäß der Differenz zwischen dem Ausgangssignal des Überwachungsmittels und der gewünschten Rate zu erzeugen.
15. System nach Anspruch 14, bei dem das Frequenzsteuermittel eine Proportional-Plus-Integral Steuerung (32) aufweist.
16. System nach irgendeinem der Ansprüche 12 bis 15, mit einem Offset-Mittel (34), das angeordnet ist, um dem Frequenzsteuersignal einen Offset (I_0) hinzuaddieren.
17. System nach irgendeinem der Ansprüche 12 bis 16, mit einem Anstiegsgeschwindigkeits-Überwachungsmittel (38), das betreibbar ist, um die An-

stiegsgeschwindigkeit des Stroms in der Wicklung zu überwachen und das Frequenzsteuersignal abzuschalten, wenn der Stromanstieg eine vorbestimmte Rate übersteigt.

18. System nach irgendeinem der Ansprüche 11 bis 16, mit einem Mittel zum Setzen des Integralsteuerausdrucks der Steuerung auf Null, wenn kein Strom in der Wicklung fließt.
19. System nach irgendeinem der Ansprüche 11 bis 18, mit einem Begrenzer (36), der angeordnet ist, um die minimale und/oder maximale Breite des Hysteresebandes zu begrenzen.

Revendications

1. Procédé de commande de courant dans une machine à réluctance commutée (28) comprenant au moins un enroulement, le procédé comprenant :

la dérivation d'un signal de courant (i_i) indicatif du courant;
la comparaison du signal de courant avec un signal indicatif d'un courant souhaité afin de produire un signal d'erreur;
le réglage d'une seule bande d'hystérésis (i_h) aux environs d'un niveau (i_{av}) indicatif d'un courant souhaité;
la commutation (24) du courant lorsque le signal d'erreur indique que le courant a traversé une limite de la seule bande d'hystérésis de manière à renvoyer le courant à l'intérieur de la bande d'hystérésis; et
la surveillance de la fréquence de commutation et l'ajustement de la largeur de la bande d'hystérésis en réponse à la fréquence surveillée de manière à ajuster la fréquence de commutation alors que la machine est en fonctionnement.

2. Procédé suivant la revendication 1, dans lequel la bande d'hystérésis est ajustée en réponse à la fréquence surveillée afin de maintenir une fréquence de commutation substantiellement à un niveau souhaité.
3. Procédé suivant la revendication 1 ou 2, comprenant la comparaison de la fréquence surveillée (F_i) avec une fréquence de référence (F_r) afin de produire un signal d'erreur de fréquence (F_e) et de générer un signal de commande basé sur le signal d'erreur de fréquence et sur une fonction de commande (PI).
4. Procédé suivant la revendication 3, dans lequel la fonction de commande est une fonction de commande proportionnelle et intégrale (PI).

5. Procédé suivant la revendication 4, dans lequel le terme intégral (I) de la fonction de commande est mis à zéro lorsqu'il ne circule aucun courant dans l'enroulement.

6. Procédé suivant l'une quelconque des revendications 3 à 5, dans lequel un décalage (I_0) est ajouté au signal de commande.

7. Procédé suivant l'une quelconque des revendications 1 à 6, comprenant la limitation de la largeur minimum et/ou maximum de la bande d'hystérésis.

8. Procédé suivant l'une quelconque des revendications 1 à 7, comprenant la dérivation (38) d'un signal indicatif de la vitesse de balayage du courant et la désactivation (39) du signal de commande lorsque le balayage dépasse une vitesse prédéterminée.

9. Procédé suivant l'une quelconque des revendications 1 à 8, comprenant la comparaison d'un signal de niveau de courant souhaité (I_d) avec le signal de courant (i_i) afin de dériver un signal d'erreur de courant (I_e), la bande d'hystérésis étant réglée autour d'une erreur de courant nulle.

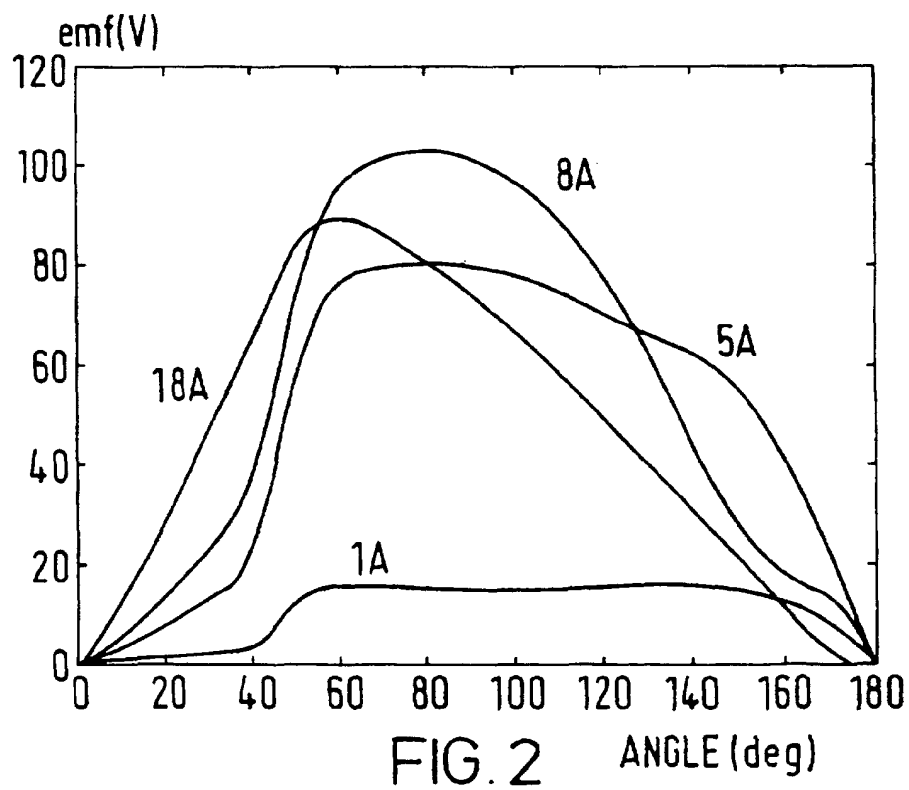
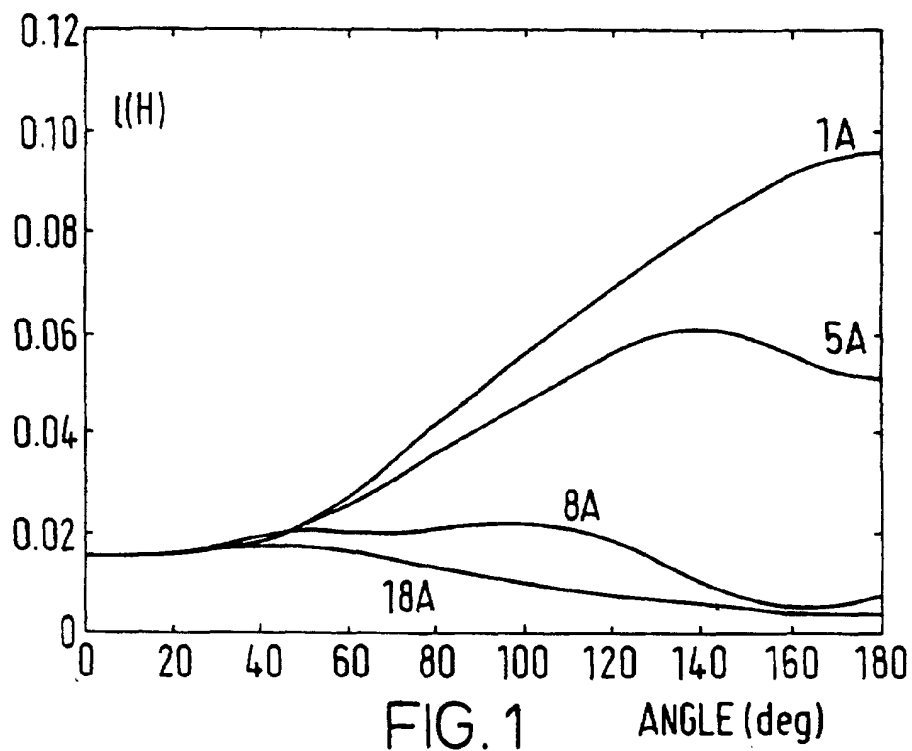
10. Procédé suivant la revendication 1, dans lequel le signal de courant est un signal de réaction (i_f).

11. Système de machine à réluctance commutée, comprenant une machine à réluctance commutée (28) équipée d'un rotor, d'un stator et d'au moins un enroulement de phase;

des moyens pour dériver un signal de courant (i_i) indicatif du courant dans l'enroulement;
des moyens de commutation (24) pouvant être actionnés pour appliquer une tension à l'enroulement;
des moyens de détection d'erreur (10) pour comparer le signal de courant avec un signal indicatif d'un courant souhaité (I_d) afin de produire un signal d'erreur (I_e);
des moyens de commande d'hystérésis (14) agencés de manière à recevoir le signal d'erreur et capables d'activer les moyens de commutation lorsque le signal d'erreur indique que le courant a dépassé un seuil d'hystérésis supérieur ou inférieur d'une seule bande d'hystérésis (i_h) afin de renvoyer le courant à l'intérieur de la bande d'hystérésis; et
des moyens de commande de fréquence (20) capables de surveiller la fréquence de commutation et d'ajuster la largeur de la bande d'hystérésis en réponse à la fréquence surveillée de manière à ajuster la fréquence de commutation alors que la machine est en fonctionnement.

12. Système suivant la revendication 11, comprenant des moyens de surveillance (18) pour surveiller la fréquence de commutation afin de produire une sortie (F_f), les moyens de commande de fréquence étant capables de générer un signal de commande de fréquence basé sur ladite sortie, les moyens de commande d'hystérésis étant sensibles au signal de commande de fréquence pour ajuster la largeur de la bande d'hystérésis. 5
- 10
13. Système suivant la revendication 12, dans lequel les moyens de commande d'hystérésis sont sensibles au signal de commande de fréquence pour ajuster la bande d'hystérésis afin de maintenir la fréquence de commutation substantiellement à un niveau souhaité. 15
14. Système suivant la revendication 13, dans lequel les moyens de détection d'erreur (16) sont agencés de manière à produire un signal d'erreur de fréquence (F_e) en fonction de la différence entre la sortie des moyens de surveillance et le niveau souhaité. 20
15. Système suivant la revendication 14, dans lequel les moyens de commande de fréquence comprennent une unité de commande proportionnelle et intégrale (32). 25
16. Système suivant l'une quelconque des revendications 12 à 15, comprenant des moyens de décalage (34) agencés de manière à ajouter un décalage (I_0) au signal de commande de fréquence. 30
17. Système suivant l'une quelconque des revendications 12 à 16, comprenant des moyens de surveillance de la vitesse de balayage (38) capables de surveiller la vitesse de balayage du courant dans l'enroulement et de désactiver le signal de commande de fréquence lorsque le balayage de courant dépasse une vitesse prédéterminée. 35 40
18. Système suivant l'une quelconque des revendications 11 à 16, comprenant des moyens pour mettre à zéro le terme de commande intégral de l'unité de commande quand aucun courant ne circule dans l'enroulement. 45
19. Système suivant l'une quelconque des revendications 11 à 18, comprenant un limiteur (36) agencé pour limiter la largeur minimum et/ou maximum de la bande d'hystérésis. 50

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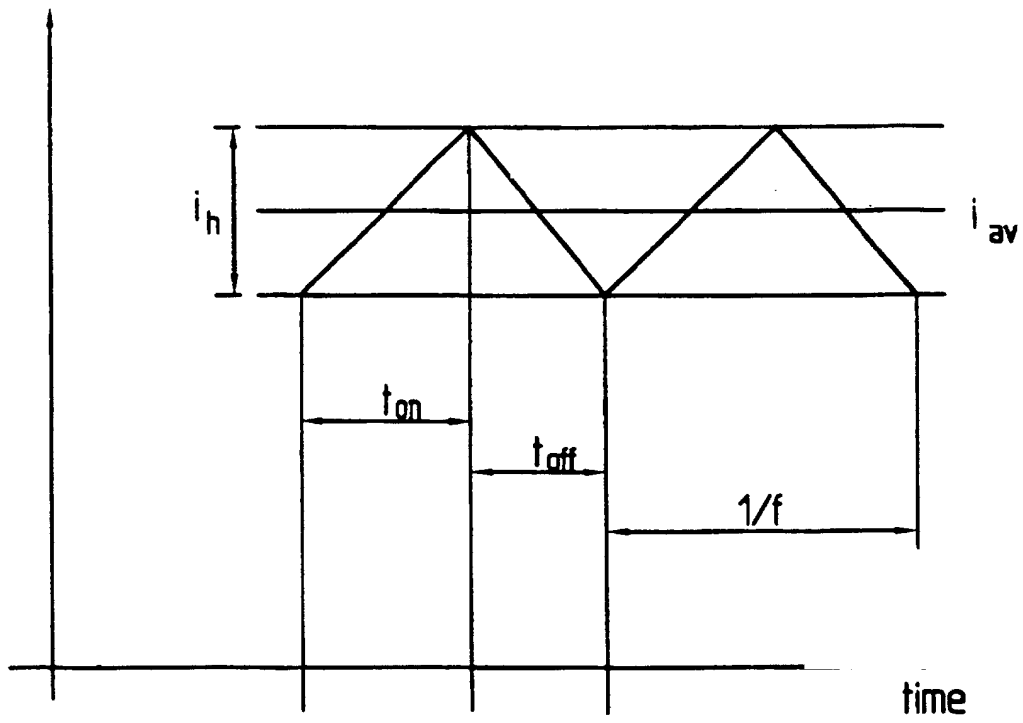


FIG. 3

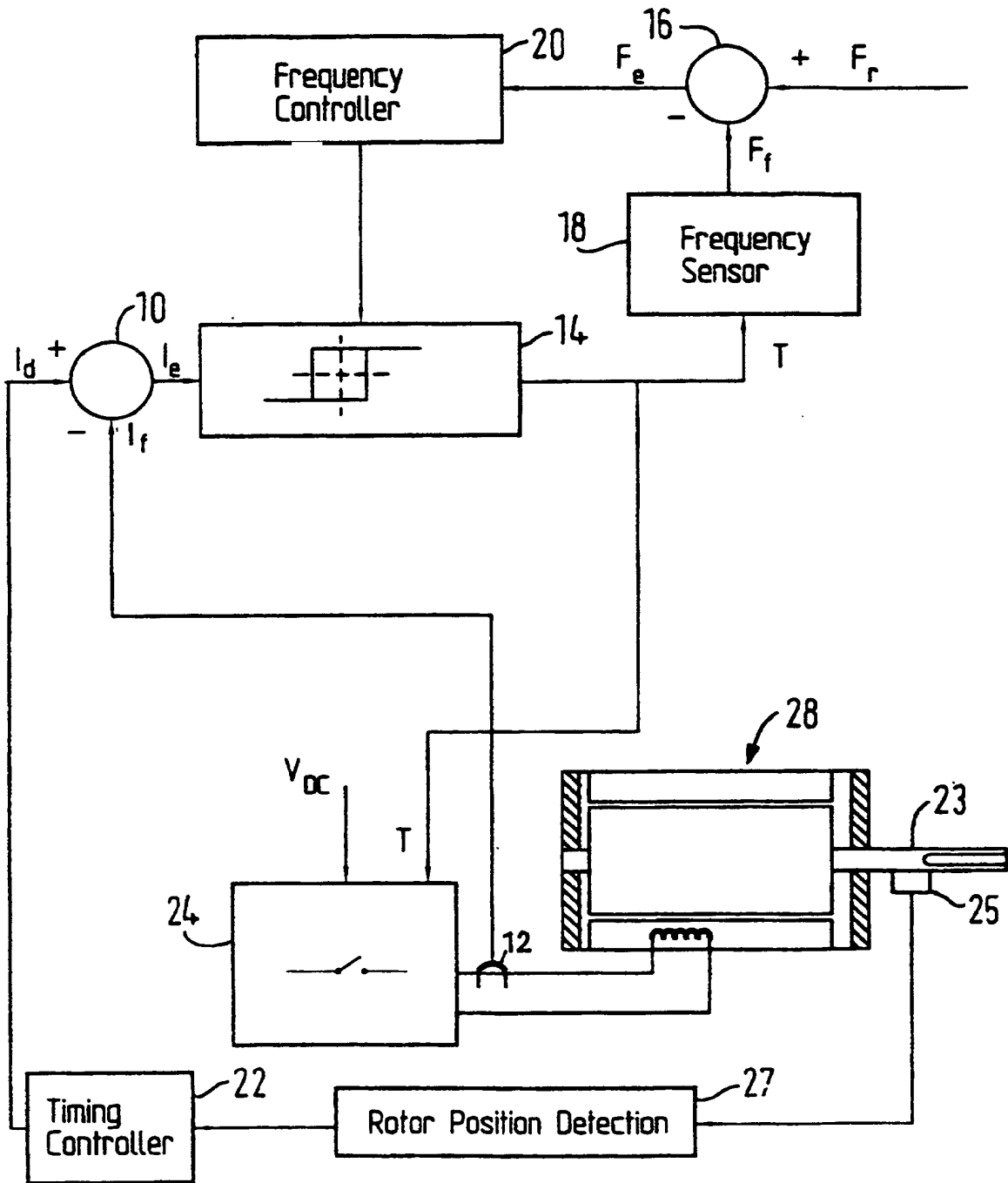


FIG. 4

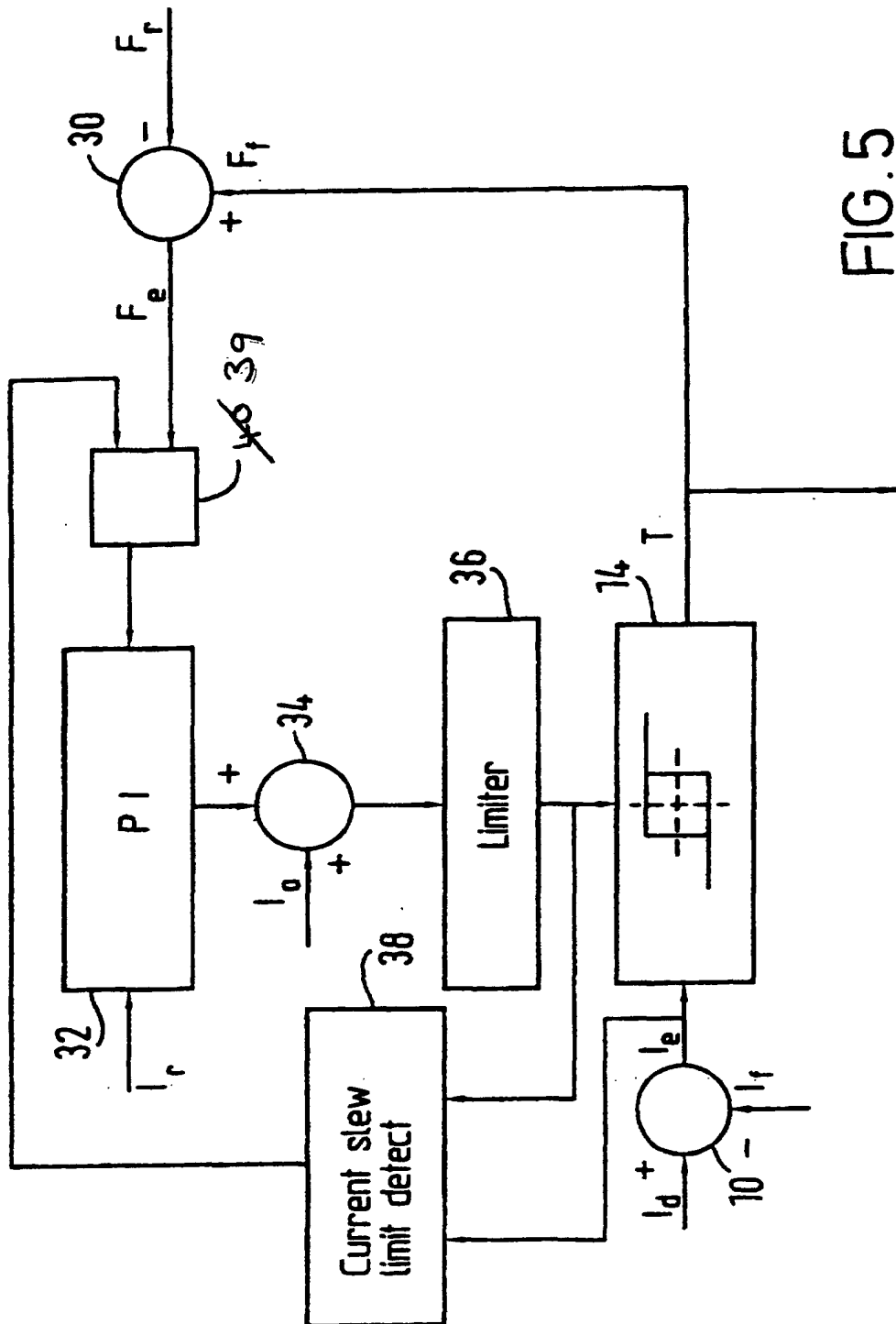


FIG. 5

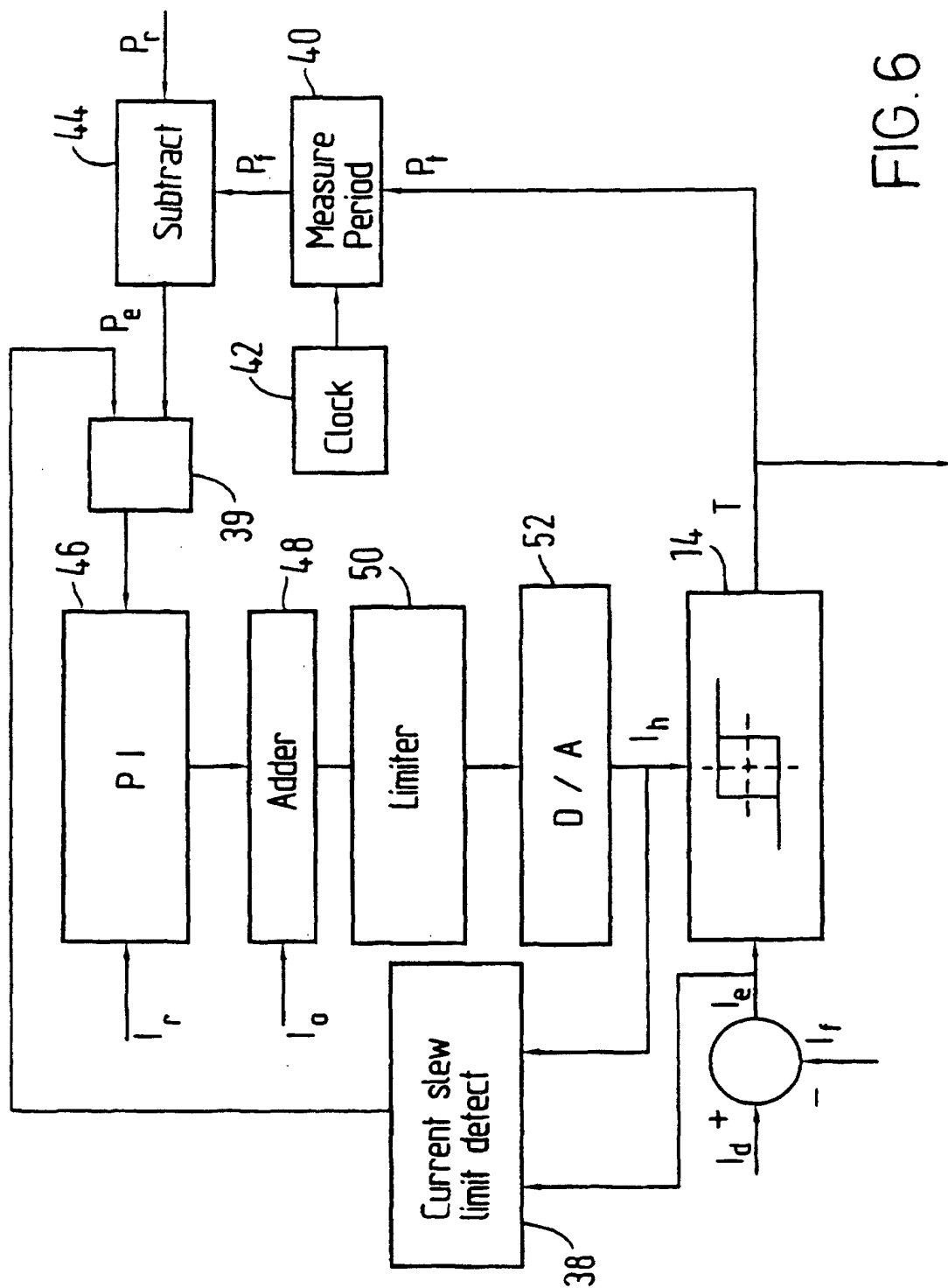


FIG. 6